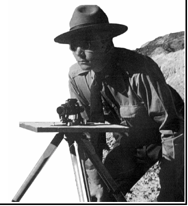
GEOLOGIC RESOURCE MONITORING PARAMETERS

Karst Processes



Brief Description: Karst is a type of landscape found on carbonate rocks (limestone, dolomite, marble) or evaporites (gypsum, anhydrite, rock salt) and is typified by a wide range of closed surface depressions, a well-developed underground drainage system, and a paucity of surface streams. The highly varied interactions among chemical, physical and biological processes have a broad range of geological effects including dissolution, precipitation, sedimentation and ground subsidence. Diagnostic features such as sinkholes (dolines), sinking streams, caves and large springs are the result of the solutional action of circulating groundwater, which may exit to entrenched effluent streams. Most of this underground water moves by laminar flow within narrow fissures, which may become enlarged above, at or below the water table to form subsurface caves, in which the flow may become turbulent. Caves contain a variety of dissolution features, sediments and speleothems (deposits with various forms and mineralogy, chiefly calcite), all of which may preserve a record of the geological and climatic history of the area. Karst deposits and landforms may persist for extraordinarily long times in relict caves and paleokarst.

Karst can be either a sink or a source of CO_2, for the karst process is part of the global carbon cycle in which carbon is exchanged between the atmosphere, surface and underground water and carbonate minerals. Dissolution of carbonates, which is enhanced by the presence of acids in water, ties up carbon derived from the rock and from dissolved CO_2 as aqueous HCO_3^-. Deposition of dissolved carbonate minerals is accompanied - and usually triggered - by release of some of the carbon as CO_2. In many karst locations, CO_2 emission is associated with the deposition of calcareous sinter (tufa, travertine) at the outlet of cold or warm springs.

Though most abundant in humid regions, karst can also be found in arid terrains where H_2S in groundwater rising from reducing zones at depth oxidizes to produce sulphuric acid, which can form large caves, such as the Carlsbad Caverns of New Mexico. Similar processes also operate in humid regions but tend to be masked by the CO_2 reaction. Sulphates and rock salt are rarely exposed in humid climates. They are susceptible to rapid dissolution during periodic rains where they are at the surface in drier terrains.

Significance: It is estimated that karst landscapes occupy up to 10% of the Earth's land surface, and that as much as a quarter of the world's population is supplied by karst water. The karst system is sensitive to many environmental factors. The presence and growth of caves may cause short-term problems, including bedrock collapse, disparities in well yields, poor groundwater quality because of lack of filtering action, instability of overlying soils, and difficulty in designing effective monitoring systems around waste facilities. Instability of karst surfaces leads annually to millions of dollars of damage to roads, buildings and other structures in North America alone. Radon levels in karst groundwater tend to be high in some regions, and underground solution conduits can distribute radon unevenly throughout a particular area. Because the great variety of subsurface voids and deposits are protected from surface weathering and disturbance, karst preserves a record of environmental change more faithfully than most other geological settings. Temperature, rainfall, nature of soil and vegetation cover, glaciation, fluvial erosion and deposition, and patterns of groundwater flow can usually be read from cave patterns and deposits. This record can be resolved on an annual scale in the case of certain fast-growing speleothems [see coral chemistry and growth patterns].

Environment where Applicable: Karst is most common in carbonate terrains in humid regions of all kinds (temperate, tropical, alpine, polar), but processes of deep-seated underground dissolution can also occur in arid regions.

Types of Monitoring Sites: Caves provide unique, productive and extensive field sites, because they allow direct observation and mapping of underground features and their relation to the surface and to groundwater flow. Furthermore, their origin, morphology and distribution patterns are the dominant factors in controlling the nature of the overlying land surface (e.g. distribution of sinkholes) and the directions of groundwater movement. Wells, borings and quarries are less useful as monitoring sites, because they provide only discontinuous points of information.

Method of Measurement: A holistic approach is required for karst studies, one that addresses the entire suite of interacting features and processes: geology, chemistry, engineering, soil science, biology, meteorology and, especially, hydrology must all be involved. Hydrological and geochemical measurements of springs, sinking streams, drip waters into caves, and cave streams provide records of short-term changes in water quality and chemical processes. The most important variables include pH, temperature, Ca, Mg, Na, Cl, HCO_3, and SO_4. Pumping tests on wells are useful in clarifying the nature of the porosity and permeability of karst aquifers, as are simple monitoring of natural changes in water levels in cave streams. Dye tracing is a useful technique for demonstrating patterns of underground flow and delineating drainage divides, which may vary with time. Studies of the mineralogy and geochemistry of cave precipitates (using X-ray diffraction, luminescence, isotope ratios and trace elements) can reveal past changes in temperature, humidity, infiltration rates and groundwater chemistry. In built-up areas it is important to locate buried cavities and to monitor their potential for collapse, using a combination of geophysical surveys, exploratory drilling and repeated levelling.

Frequency of Measurement: Surface features and soils in karst terrains are notoriously unstable and can change rapidly, commonly at catastrophic rates. In humid climates, most surface collapses occur during or soon after floods, when soil and debris is eroded from beneath incipient sinkholes. Groundwater chemistry and contamination change so rapidly during floods that continuous measurements are needed in order to interpret the karst system.

Limitations of Data and Monitoring: Surface studies of karst are hampered by the fact that surface features are controlled by underground water movement, without knowledge of which it is impossible to interpret the surface features properly. Changes in karst are often so sudden that it is difficult to design a valid monitoring strategy.

Possible Thresholds: The slow, gradual movement of soil tends to fill depressions in the karst bedrock surface, keeping pace with the solutional growth of sinkholes. However, where this material can be transported away from the site by cave streams, an arch of rock and soil can be produced over an underground void, resulting in sudden collapse. The threshold between gradual and catastrophic subsidence is not generally predictable from the surface. There is, however, an important threshold between dissolution and precipitation, which is governed by the degree of saturation of karst water with respect to minerals, especially calcite. The threshold can be crossed for a number of different reasons, with CO_2 level enhanced by decay processes and reduced by aeration. Calcite and CO_2 solubility both decrease with temperature, but high temperatures generate greater CO_2 production, which in turn offsets the diminution of CO_2 solubility. Solution conduits form along paths of greatest groundwater discharge, with their rate of enlargement at first determined by discharge rates and saturation concentration. Once the water is able to pass through the conduit without exceeding the threshold for calcite solubility (about 70% saturation), the enlargement rate becomes almost independent of discharge and is determined by dissolution kinetics.

Key References:

Beck, B.F. 1989. Engineering and environmental implications of sinkholes and karst. Rotterdam: Balkema.

Ford, D.C. & P.W.Williams 1989. Karst geomorphology and hydrology. London: Unwin Hyman.

Jennings, J.N. 1985. Karst geomorphology Oxford: Basil Blackwell.

White, W.B. 1988. Geomorphology and hydrology of karst terrains. Oxford: Oxford University Press.

Related Environmental and Geological Issues: Flooding of caves in highly populated areas can disperse contaminants over wide areas. For example, in the mid-1980s, flood-induced ponding of water under high pressure in caves beneath the city of Bowling Green, Kentucky dispersed hydrocarbons (from industrial wastes) throughout many fissures, bringing their concentration to nearly explosive levels in overlying basements and nearby wells. Under steep hydraulic gradients, fissures may enlarge sufficiently to cause significant leakage through the ground during a human lifetime, as around some of the Tennessee Valley Authority dams in the mid-twentieth century. The most vexing problem in karst today is the lack of rational regulations concerning groundwater monitoring, a situation complicated by a common misunderstanding of the great differences in flow behaviour between karst and non-karst (porous-media) aquifers.

Overall Assessment: Karst landscapes are particularly dynamic and subject to rapid change. They preserve a valuable record of environmental change, and should be monitored closely for their effect on human settlements and built structures.

Source: This summary of monitoring parameters has been adapted from the Geoindicator Checklist developed by the International Union of Geological Sciences through its Commission on Geological Sciences for Environmental Planning. Geoindicators include 27 earth system processes and phenomena that are liable to change in less than a century in magnitude, direction, or rate to an extent that may be significant for environmental sustainability and ecological health. Geoindicators were developed as tools to assist in integrated assessments of natural environments and ecosystems, as well as for state-of-the-environment reporting. Some general references useful for many geoindicators are listed here:

Berger, A.R. & W.J.Iams (eds.) 1996. Geoindicators: assessing rapid environmental change in earth systems. Rotterdam: Balkema. The scientific and policy background to geoindicators, including the first formal publication of the geoindicator checklist.

Goudie, A. 1990. Geomorphological techniques. Second Edition. London: Allen & Unwin. A comprehensive review of techniques that have been employed in studies of drainage basins, rivers, hillslopes, glaciers and other landforms.

Gregory, K.J. & D.E.Walling (eds) 1987. Human activity and environmental processes. New York: John Wiley. Precipitation; hydrological, coastal and ocean processes; lacustrine systems; slopes and weathering; river channels; permafrost; land subsidence; soil profiles, erosion and conservation; impacts on vegetation and animals; desertification.

Nuhfer, E.B., R.J.Proctor & P.H.Moser 1993. The citizens' guide to geologic hazards. American Institute for Professional Geologists (7828 Vance Drive, Ste 103, Arvada CO 80003, USA). A very useful summary of a wide range of natural hazards.